

Final Report – Option 1

“Photonics, metamaterials and physics in Australasia”

AOARD 09-1-4162

Alexander J. Glass

This report covers the activities of the grantee in CY 2009, prior to and during the period of performance of the Grant. The Statement of Work for this period is as follows:

The grantee shall investigate the states of the art within Australasia of research in photonics, metamaterials and physics. Tasks will include providing authoritative assessment of progress and opportunities for investment. Payment will be made upon receipt and acceptance of the detailed work plan that shows milestones. This plan is due no later than one month after award of the Grant. The grantee must also submit a final report at the end of the four-month project.

I. Summary of Grantee Activities:

In order to carry out the activities specified in the statement of work it was necessary for the grantee to maintain close liaison not only with AOARD, but also with subject matter specialists in AFOSR and in AFRL and cooperating laboratories. The grantee carried out the following trips prior to or during the contract period:

3-5 Feb 2009 – XOARD Off-site in San Francisco

This was a meeting attended by representatives of AOARD, EOARD, SOARD and AFOSR, to review the performance of the overseas offices and make recommendations for improvement. A written report was drafted and circulated for comment.

27 Mar – 10 Apr -- travel to Australia

The grantee visited the University of Adelaide, the Australian National University and the University of Sydney, and attended the Eighth International Conference On Photonic and Electromagnetic Crystal Structures (PECS VIII) in Sydney. This conference was sponsored by both AOARD and AFOSR. A detailed report on photonics activities in Australia comprises the second part of this document.

20- 21 April -- Taiwan nanoscience workshop in San Francisco

This workshop was convened by Harold Weinstock of AFOSR to review the collaborative program between AFOSR and Taiwan on nanotechnology. The meeting was attended by scientists from several universities and laboratories in Taiwan and universities and Air Force laboratories in the US. Several topics were discussed, including solar cells, organic electronic materials, new polymers, and new nanoscale fabrication techniques.

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14. ABSTRACT <p>This report covers the activities in 2009 on an effort to investigate the states of the art within Australasia of research in photonics, metamaterials and physics. Tasks included providing authoritative assessment of progress and opportunities for investment. The focus is on research in Australia, Taiwan, and Japan.</p>						
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7- 8 July – AFOSR ceramic laser review in Los Angeles

This program review was convened by Dr. Joan Fuller of AFOSR to discuss recent developments in ceramic optical materials, especially ceramic lasers. It was attended primarily by scientists from US government laboratories and universities, as well as Dr. Akio Ikesue from the World Laboratory in Nagoya, Japan. Dr. Ikesue's research is currently supported by AOARD.

16-18 Aug – Visit to AFRL and JTO in Albuquerque

Dr. Kumar Jata of AOARD and I visited laser research scientists at Kirtland AFB to discuss AFRL interests in photonics research in Australasia. We also met with representatives of the Joint Technology Office. A summary of these visits is included as part IV of this document.

23-28 Aug – Air Force Scientific Advisory Board review of AFOSR programs in Arlington, VA.

The Air Force Scientific Advisory Board reviewed the all programs of the Air Force Office of Scientific Research. This was an excellent opportunity to obtain a high level picture of the scope of activities within the office and to hear the response of the reviewers to the presentations by the overseas offices in particular.

Additional activities: The following two proposals were reviewed by the grantee, and recommendations were transmitted to Dr. Kumar Jata at AOARD.

“Average Power And Brightness Scaling Of Diamond Raman Lasers” by Richard Mildren, Macquarie University, Sydney, Australia

“Advanced Ceramic Gain Media with Broadband For High Energy Laser” by Akio Ikesue, World Lab Ltd., Nagoya, Japan

II. Visit to Australia

A) University of Adelaide

The first site that I visited in Australia was the University of Adelaide. I visited the University of Adelaide on Monday, March 30 and Wednesday, April 1, 2009. During that time, I met with Professor Jesper Munch (pronounced Yes-per Monk), former head of the Physics Department, Professor Tanya Monro, currently Chair of Photonics and the Director of the Center of Expertise in Photonics, and soon to be Director of the Institute for Photonics and Advanced Sensing, Associate Professor Peter Veitch, current Head of Physics, and Associate Prof Murray Hamilton. Professor Munch came to Adelaide in 1990, to establish an optics capability in the Physics Department. He had worked previously at TRW (now Northrop-Grumman) in the US as well as other aerospace companies. His particular expertise is in laser physics, including frequency stable high power solid-state lasers.

Much of his work in Adelaide has focused on the design of low-noise lasers for use in the detection of gravitational waves. He has pioneered the development of so-called “stable/unstable resonators” for low noise operation. Australia is developing a site called the Australian International Gravitational Observatory (AIGO) as part of a world-wide network for detection of gravitational waves. This research ceased when the international community decided to use a competing design developed by Laser-Zentrum Hannover in Germany.

Munch is looking at applications for his stable high-power laser designs in space and military missions. For example, he is interested in developing cryogenic solid-state lasers for space applications, and is doing so in collaboration with Northrop Grumman. The state of South Australia (SA) has targeted defense and space technology as a growth area, in part because of the location of various space and military facilities in SA, and because of the location there of defense contractors like British Aerospace.

When Professor Munch first came to Adelaide, the Physics department was in need of rejuvenation. He set about attracting energetic young scientists working in frontier areas of science to the department. In 2005, he persuaded Dr. Tanya Monroe, who was a Professor at the University of Southampton in the UK, to come to Adelaide and set up a research center in fiber optics, specializing in “soft” fibers, i.e., non-silicate fibers transmitting in the IR, with applications to sensing and special functions, rather than long-haul communications. Professor Monroe had worked on kilowatt fiber lasers at Southampton under DARPA sponsorship, and received support at Adelaide from the Australian Defense Science Technology Organisation (DSTO). She was able to recruit several experienced fiber optics specialists from Southampton. She was given the position as Director of the Centre of Expertise on Photonics and also was awarded a Federation Fellowship, one of the most prestigious awards given to Australian researchers, which are primarily used to attract Australian scientists working overseas back to Australia. (Professor Ben Eggleton, who chaired the PECS-VIII conference in Sydney, is also a Federation Fellow).

Needing more space, she then applied for and received a building grant from the Higher Education Endowment Fund, a federal government program, in the amount of \$35 Million. The University of Adelaide will provide additional funds totaling one-fifth of the building grant amount (\$6 Million) to support the growth of research capacity. Professor Monroe showed me the plans for her new building, which will nearly double the size of the Physics department space. Her goal is to have 100 researchers in her laboratory within three years.

Research in Professor Monroe's laboratory is currently concentrated on research and development in the area of soft glass optical fibres. Compositional studies are led by Dr Heike Ebendorff-Heidepriem, who came with Prof. Monroe from Southampton, and serves as Deputy Director of the Center. Soft glass performs are fabricated by extrusion through dies, a technique originally developed by Monroe's group while in Southampton. Fibers are drawn on a 4 ½ meter tower. A 6 meter tower will be installed as part of the new facility.

Monroe is very interested in both microstructured fibers and highly nonlinear fiber materials. Her group has recently obtained the highest values of optical nonlinearity of any optical fiber at 1.55 μm in bismuth glass. She also collaborates with Ben Eggleton's Institute (CUDOS) on metamaterials research, including placing nanowires in optical fibers to create plasmonic resonances.

I also met with Associate Prof. Murray Hamilton, who is working on compact diode laser sources for atmospheric water vapor measurements. He also is collaborating on a project to develop biomimetic sensors based on insect eye structures with a physiologist and a software engineer. He is seeking funding for both projects.

B) Australian National University

I visited the Australian National University in Canberra on Thursday, April 2 and Friday, April 3, 2009. While there, I spoke with Dr. Anna Samoc and Professor Barry Luther-Davies as well as

Dr. Ilya Shadrivov, who was representing Professor Yuri Kivshar, all from the Research School of Physical Sciences and Engineering. Dr. Samoc, whom I had met before at a conference in India, hosted my visit.

Dr. Samoc and her husband, Dr. Marek Samoc, have been funded in the past by AOARD, with funds from Dr. Charles Lee at AFOSR, and have collaborated extensively with Dr. James Grote of AFOSR on the evaluation of DNA as a material for nonlinear optics. Marek Samoc held a professorial position at ANU until recently, but has accepted a position at the University of Wroclaw in Poland, with the intention of dividing his time between the two schools. However, ANU will not allow him to continue as a Professor on a part-time basis. Dr. Anna Samoc is continuing at ANU as a visiting scholar, but is not receiving a salary from the university. She is primarily interested in the development of new organic materials for nonlinear optical applications, and is an expert in techniques to measure nonlinear coefficients of new materials.

Dr. Kivshar collaborates closely with Ben Eggleston at the University of Sydney on photonic crystals and metamaterials. Dr. Kivshar is primarily a theorist, but supervises experimental thesis research. Professor Luther-Davies leads a fairly large group of researchers. He is the head of the Laser Physics Centre, and his research emphasizes chalcogenide glasses (in collaboration with Tanya Monro's group) and telecommunication applications of lasers and nonlinear optics. I urged him to submit a research proposal to AOARD, but so far, he has not responded.

C) PECS Conference

My primary purpose of going to Australia was to attend the Eighth International Photonic and Electromagnetic Crystal Structures Conference (PECS-VIII). The conference was organized and chaired by Professor Ben Eggleston of the University of Sydney and Prof. Yuri Kivshar of ANU. It is one of the leading conferences on the subject, and attracted over 200 attendees from Europe, the US, Asia and Australia. 211 papers were presented, either as oral or poster presentations. A complete listing of the conference program and other details can be found on the Web at < <http://pecs8.mtci.com.au/>>.

The field of photonic crystals was started about twenty years ago by Eli Yablonovich and co-workers, who recognized that advances in microtechnology made it possible to construct periodic structures with lattice spacing comparable to a wavelength of light. The properties of periodic structures have been known for many years, since the work of Lord Rayleigh in the 19th century and Leon Brillouin early in the 20th century. Further advances in both fabrication and understanding have allowed the construction and analysis of structures on a scale comparable to molecular dimensions, giving rise to the field of metamaterials, which combine photonic crystal structures with molecular engineering. The materials offer the promise of controlling the generation and propagation of electromagnetic waves with exquisite precision, and lead to a number of fascinating potential applications, including materials with negative index of refraction, and "slow" and trapped light.

Most of the leading researchers in the fields of photonic crystals and metamaterials gathered in Sydney for PECS VIII, and the conference provided a comprehensive overview of the current state of research, and of the leading research institutions and individuals in the field.

III. Leading scientists in Australasian Photonics

There are two world-class centers for photonics research in Australia. One is Tanya Monro's Centre of Expertise in Photonics within the School of Chemistry & Physics (CoEP) at the University of Adelaide, which emphasizes IR fibers and structured fibers. The other center of excellence in Australia in photonics-related research is the Center for Ultrahigh-Bandwidth Devices for Optical Systems (CUDOS), which is a research consortium involving six Australian universities: the University of Sydney, Macquarie University, the University of Technology (Sydney), the Australian National University, and Swinburne University of Technology.

The Director of CUDOS is Ben Eggleton (University of Sydney), and the Deputy Director is Yuri Kivshar (Australian National University). Prof. Eggleton received his education at the University of Sydney, spent some time at the Bell Laboratories in the US, and then returned to Australia in 2003. His research includes photonic crystals, slow light (metamaterials), all-optical signal processing and micro-fluidics. Like Professor Monro, he is an ARC Federation Fellow, a prestigious award given to Australian scientists who have distinguished themselves in overseas careers, and who then return to Australia. As is mentioned above, Prof. Kivshar is head of a theoretical group at ANU which is populated primarily by former Soviet scientists. Kivshar is the leading photonics theorist in Australia, and his research is highly productive and widely cited. He works closely with the experimental groups, and even supervises experimental thesis research. His primary interest is non-linear processes in photonic systems, including optical solitons in periodic structures.

Also at ANU, Professor Barry Luther-Davies is head of the Laser Physics Centre, which is affiliated with CUDOS. His interests are wide-ranging, including technologies for high-speed rf and photonics networks (with Prof. Eggleton), nano-imprinted polymer optical waveguides, and tellurite glasses (with Tanya Monro). He also has developed a novel laser source for generation of tunable 589 nm radiation for use in the Na D-line guide star.

The leading CUDOS researcher at Swinburne University is Professor Min Gu, the Director of the Centre for Micro-Photonics. His research interests include metal and metallo-dielectric photonic crystals, and super-continuum light sources. The research carried out under the CUDOS arrangement is highly collaborative, and typically, papers include authors from several of the participating institutions.

Other Asian scientists who are leaders in the fields of nano-photonics and plasmonics include Prof. Susuma Noda (Univ. of Kyoto), Prof. Toshihiko Baba (Yokohama National Univ.) Dr. Masaya Notomi (NTT Basic Research Lab) and Prof. Satoshi Kawata, Director of the Photonics Advanced Research Center at Osaka Univ., who is also affiliated with RIKEN. Finally, I was very impressed by the capabilities of KAIST in precision optical manufacturing, including development of economical mass production techniques.

IV Visits in Albuquerque

At Kirtland AFB, we visited several scientists in the Directed Energy (DE) directorate. Bill Baker is currently the Chief Scientist of the directorate but he is scheduled to retire January. Ms. Susan Thornton is the DE Director. We met briefly with Dr. Baker, who expressed considerable interest in using the contacts available in Asia through AOARD. Among the scientists we met with were Ron Kaspi (mid-IR lasers), Tim Newell, who provided some valuable insights concerning research in Australia, Pete Latham, who indicated an interest in testing ceramic materials on his thin-disk laser test bed, and Tim Madden and Lt. Col. Leanne Henry, who are leading the COIL project.

At the Joint Technology Office (JTO), we met with Mark Neice, the Director, and Don Seely, the Assistant Director. JTO has 10 people in Albuquerque. They have a budget of \$65 Million a year in 6.1 to 6.3 projects, and their mission is to find technology gaps and fund solutions. Multi-year programs are possible for them to support. They collaborate with both DOE and DoD elements. Harro Ackermann, who was formerly at AFRL in the DE directorate, is in the JTO, and helped to arrange our visit there.